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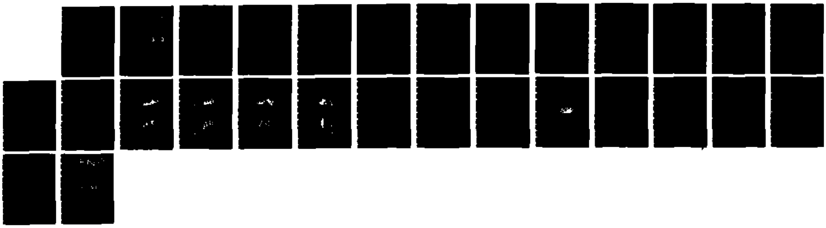

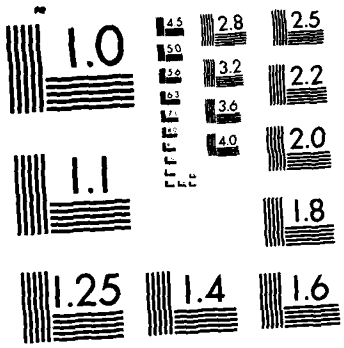
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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20084

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HULL FORM PARAMETERS FOR IMPROVED SEAKEEPING AND REDUCED RESISTANCE

by

David A. Walden

and

Paul J. Kopp

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

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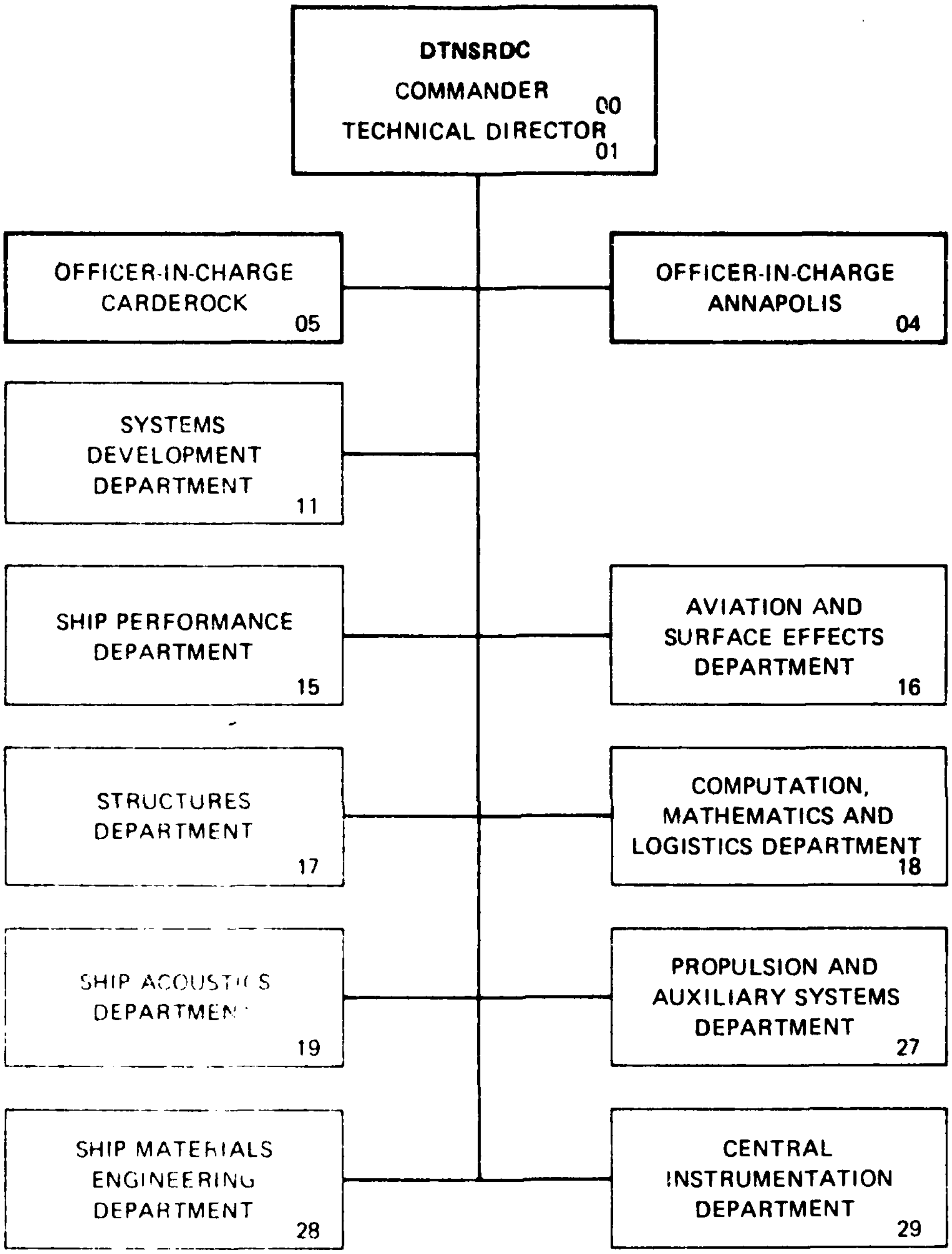

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The results of a study on seakeeping and resistance optimized frigate hull forms are presented. The seakeeping optimization is based on the work of Walden and Grundmann. Resistance calculations are based on the method of Holtrop. The effects of cost function weighting factors are discussed.

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NOTATION

C_M	Midship section coefficient
C_{VPF}	Vertical prismatic coefficient forward
C_{VPA}	Vertical prismatic coefficient aft
C_{WPF}	Waterplane coefficient forward
C_{WPA}	Waterplane coefficient aft
L	Length
T	Draft
∇	Displacement (m^3)

ABSTRACT

The results of a study on seakeeping and resistance optimized frigate hull forms are presented. The seakeeping optimization is based on the work of Walden and Grundmann. Resistance calculations are based on the method of Holtrop. The effects of cost function weighting factors are discussed.

ADMINISTRATIVE INFORMATION

This work was performed by the David Taylor Naval Ship Research and Development Center (DTNSRDC), Code 1561. Funding was provided by Energy R&D Office, Code 2759, under Work Unit Number 2759-339.

INTRODUCTION

The objective of this project was to develop a method for designing frigate hull forms that exhibit superior seakeeping qualities and improved resistance characteristics. This method can be used in support of the feasibility design of the FFX.

BACKGROUND

In order to develop hull forms with the desired qualities of good seakeeping and low resistance, a method of quickly obtaining the ship seakeeping responses and resistance is needed. Model testing is too costly and time consuming for feasibility design work. Optimization methods appear to be a useful way to investigate variations in hull forms and produce a satisfactory combination of parameters. Walden and Grundmann[1*] discuss the problems with and methods of performing seakeeping optimization.

The intention was to systematically investigate the seakeeping and resistance performance of a large number of hull forms in a search for those with a combination of both good seakeeping and low resistance. The level of detail in the hull form description was limited to that typically available at feasibility design stage. By automating the hull form parameter selection, hull form generation and performance assessment, it is possible to examine a very large number of hull forms.

*A complete listing of references is given on page 5.

The method must also allow constraints due to requirements other than seakeeping and resistance to be placed on the hull forms. These can include minimum draft for sonar immersion, minimum displacement for payload, maximum length to beam ratio for structural considerations, etc.

DESIGN PROCEDURE

The optimization technique used in this investigation was the same as that discussed in Reference 1. The same set of motion criteria as well as geometric constraints were used. The critical wave height, as explained in Reference 1, is that wave height at which one of the motion criteria (slamming, pitch, or vertical acceleration at the forward perpendicular) is exceeded. The cost function to be minimized was modified to allow weighting of the average critical wave height and the bare hull resistance. The parameters searched as well as the ranges of variation are shown in Table 1.

In order to determine the bare hull resistance (EHP) for a given set of hull form parameters, a resistance prediction method based on that described in Reference 2 was used. This method is based on a regression analysis of model and full scale test data. The equations are given for the components of the total resistance, i.e., frictional, wavemaking, appendage, transom, bulbous bow, and model-ship correlation. For this study, the only components considered were frictional, wavemaking, transom, and correlation resistance.

Three cases were investigated, namely: (i) maximizing the seakeeping performance, (ii) maximizing the resistance performance and (iii) maximizing a weighted combination of both seakeeping and resistance performance. Each of the three cases was investigated at ship speeds of 10, 20, and 30 knots. Two optimization methods are used in this study. A modified exponential random search was used to search for a global minimum of the cost function. The random search results are then used as the starting point for a direct search optimization, which refines the result. The optimization methods are discussed in References 1, 3, and 4. This approach of using the two types of optimization methods allows for a relatively high degree of certainty in actually finding an "optimum."

The combination case mentioned in the previous paragraph requires further discussion regarding the cost function. The cost function is specified by

$$\text{cost} = (\text{seakeeping weight}) \times \text{critical wave height} + (\text{resistance weight}) \times \text{EHP}$$

and has to be minimized during the optimization procedure. The weighting for the critical wave height and resistance are developed in the same manner, so the following description for the wave height weighting applies to the resistance weighting as well. At 10 knots for example, the critical wave height for the 10-knot seakeeping ship is greater than the critical wave height for the 10-knot resistance ship. The resistance of the seakeeping ship is also greater than that of the resistance ship. The inverse of the difference between the two wave height values was used as the wave height weighting for the combination ship at 10 knots while the inverse of the difference between the two resistance values was used for the resistance weighting in the cost function. This approach is also used for the other ship speeds. Such a weighting procedure is required to normalize the seakeeping performance specified by significant wave height in meters and the resistance performance given in EHP. By changing these weights, it is possible to control the relative influence of seakeeping and resistance on the design. It will be shown that by varying these weights, it is possible to describe a curve of "best ships" ranging from best seakeeping with little consideration of resistance to best resistance with a little consideration of seakeeping. These weighting factors are developed from the results of the random search but are also used as the weights in the direct search. The weights used are shown in Table 2.

OPTIMIZATION RESULTS

The results of the optimizations are presented in terms of the seakeeping and resistance characteristics, and the hull form parameters. Table 3 gives the critical wave heights and the EHP for each of the ships at 10, 20, and 30 knots. Table 4 gives the hull form parameters of the ships in Table 3. Critical wave height curves are presented in Figure 1 for the seakeeping, resistance, and combination ships. The EHP curves are presented in Figure 2.

It can be seen from Tables 3 and 4 that the 10- and 20-knot seakeeping ships are in fact the same ship. This is also true of the 20- and 30-knot resistance ships. The reason for the two seakeeping ships being identical is that at 10 and 20 knots pitch limits tend to govern while at 30 knots slamming becomes more important. Further discussion is given in Reference 1. The 20- and 30-knot resistance ships are the same because at low speeds (10 knot resistance ship), the driving influence is wetted surface while at the higher speeds, wavemaking dominates.

Figures 3, 4, 5, and 6 show the trends of critical wave height and EHP versus C_{WPF}, C_{WPA}, C_{VPF}, and C_{VPA}, respectively. These plots were obtained from the combined set of reasonable ships considered in the seakeeping, resistance, and combination optimizations. The important point to notice here is that the trends between each parameter in the figures and EHP and critical wave height are in general opposite. Better resistance ships tend to have a lower C_{WPF} and C_{WPA}, while larger values increase the wave height. Similar trends can be observed in C_{VPF} and C_{VPA}.

Body plans, design waterline curves, and sectional area curves for the 20-knot ships are given in Figures 7 through 9. Notice that the 20-knot combination ship has the forebody of the seakeeping ship and the afterbody of the resistance ship. This is not surprising in light of the information that may be obtained from Figures 3, 4, 5, and 6. The trend of EHP with C_{WPA} and C_{VPA} is stronger than that of the critical wave height. The converse is true for C_{WPF} and C_{VPF}.

Figure 10 shows the EHP plotted against the critical wave height for the combined set of 20-knot ships. The lower left side of the plot is where the optimal resistance ships are, while on the extreme right side are the optimal wave height ships. Between these two extremes are the optimal combination ships.

CONCLUSIONS

The combination of a procedure for generating a hull form from a set of coefficients, a simple seakeeping measure of merit, a resistance estimation procedure, and an optimization program has resulted in a powerful tool for use in early design.

Future work is needed in improving the resistance estimation procedure, applying more powerful optimization techniques requiring fewer iterations, improving the constraints on combinations of hull form parameters to ensure that all ships considered are "reasonable", and improving the seakeeping criteria used in calculating the limiting wave heights.

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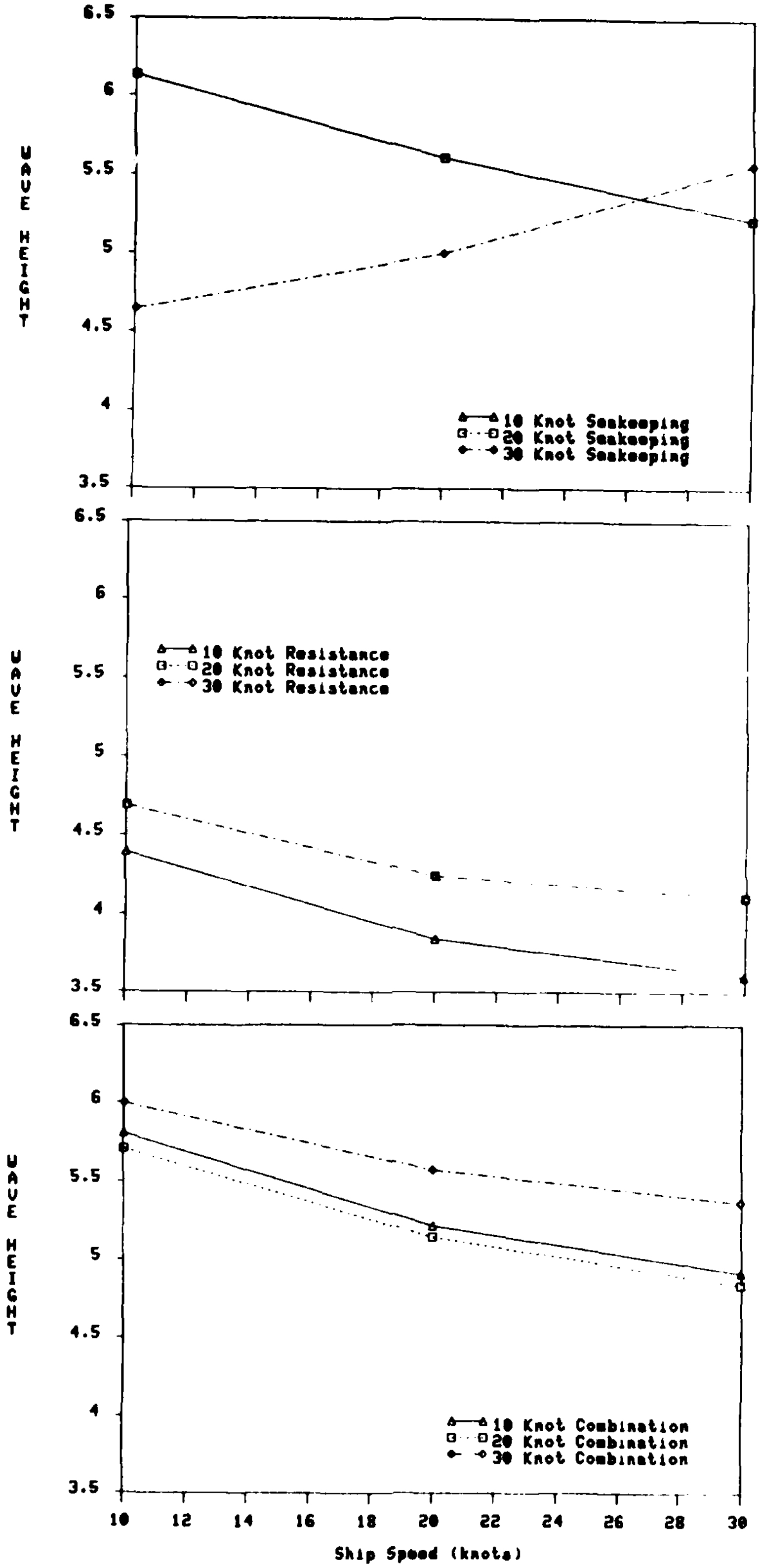

Figure 1 - Wave Height Curves

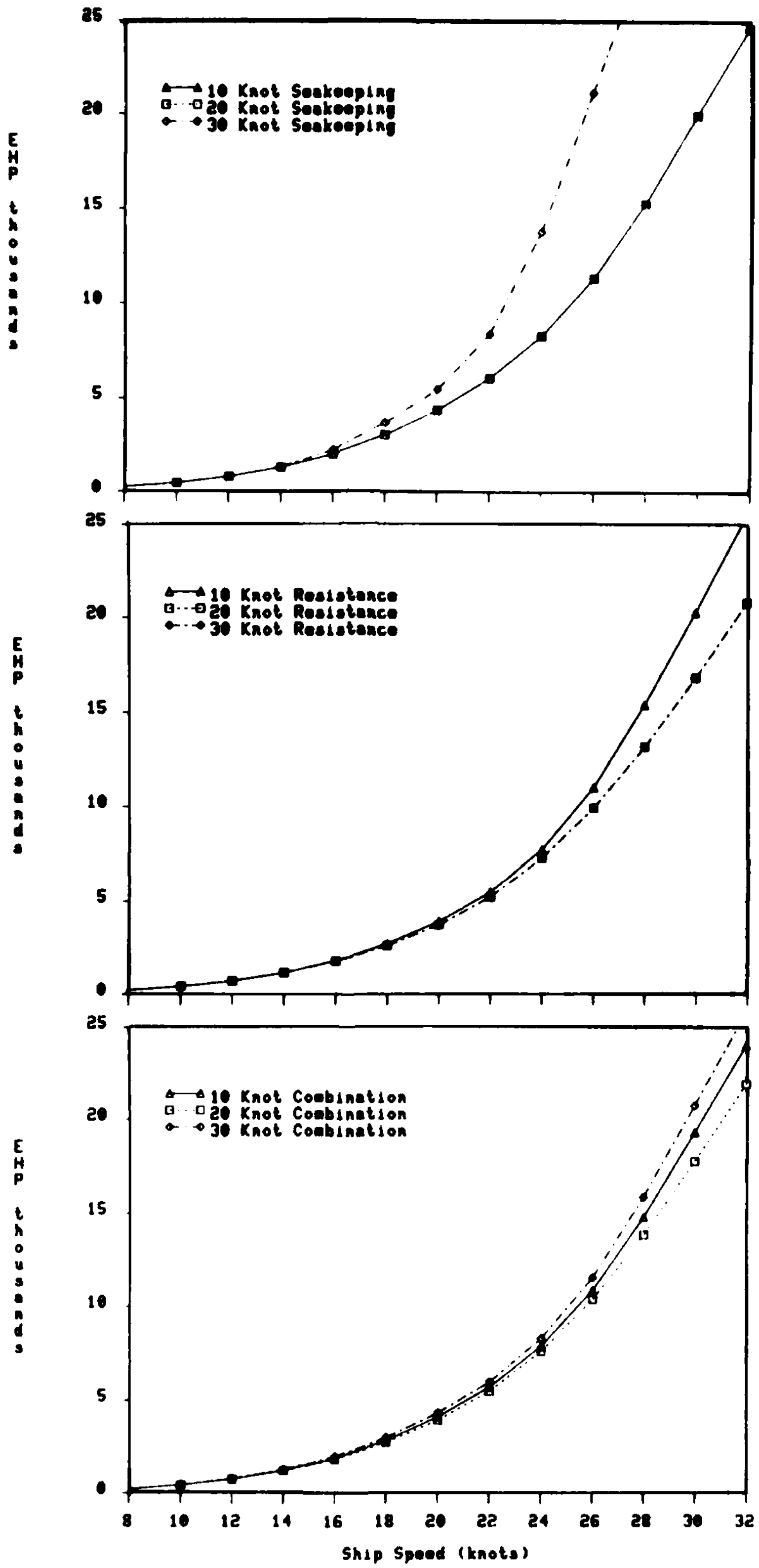

Figure 2 - EHP Curves

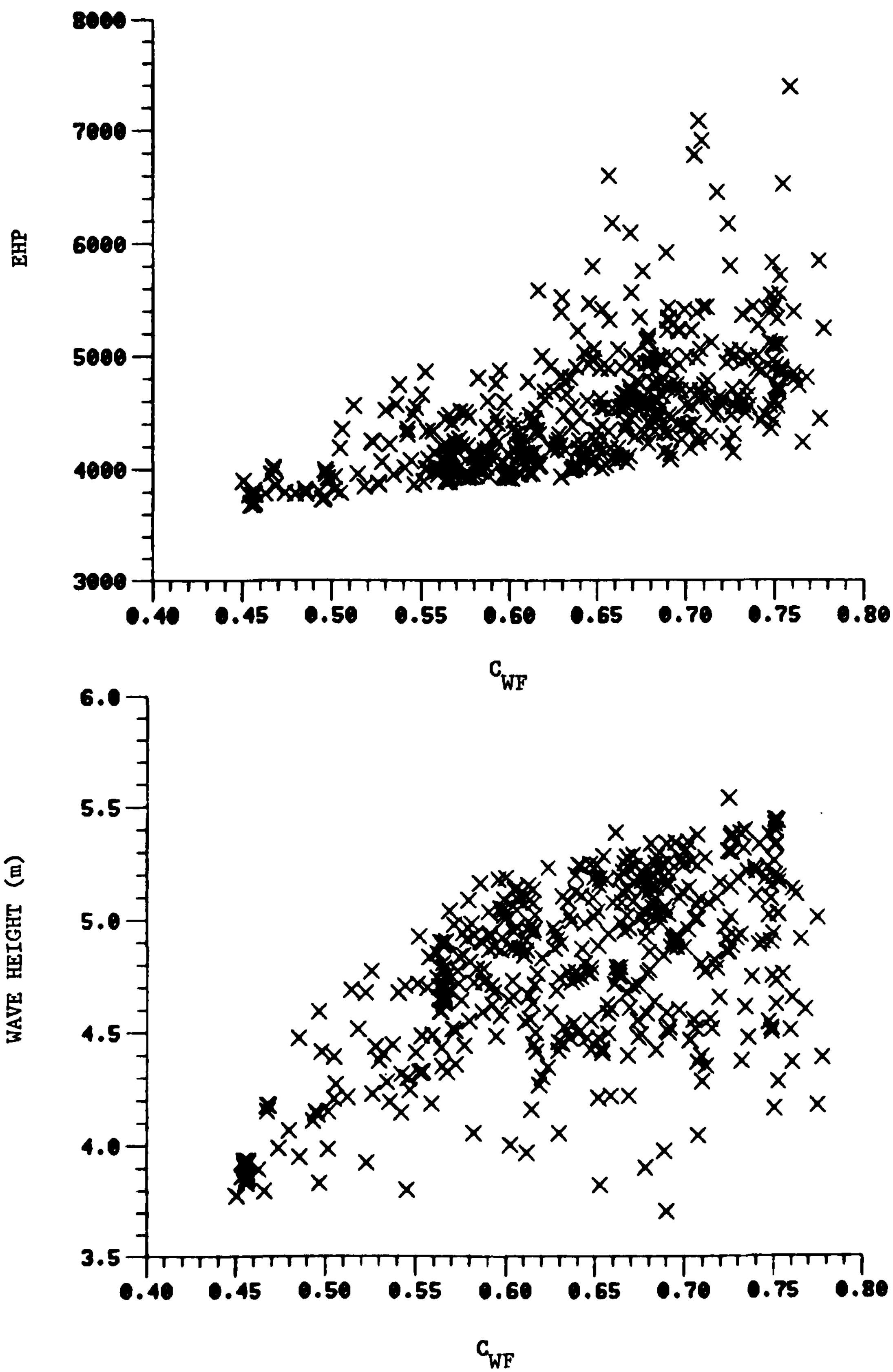

Figure 3 - Wave Height and EHP versus Water Plane Coefficient Forward

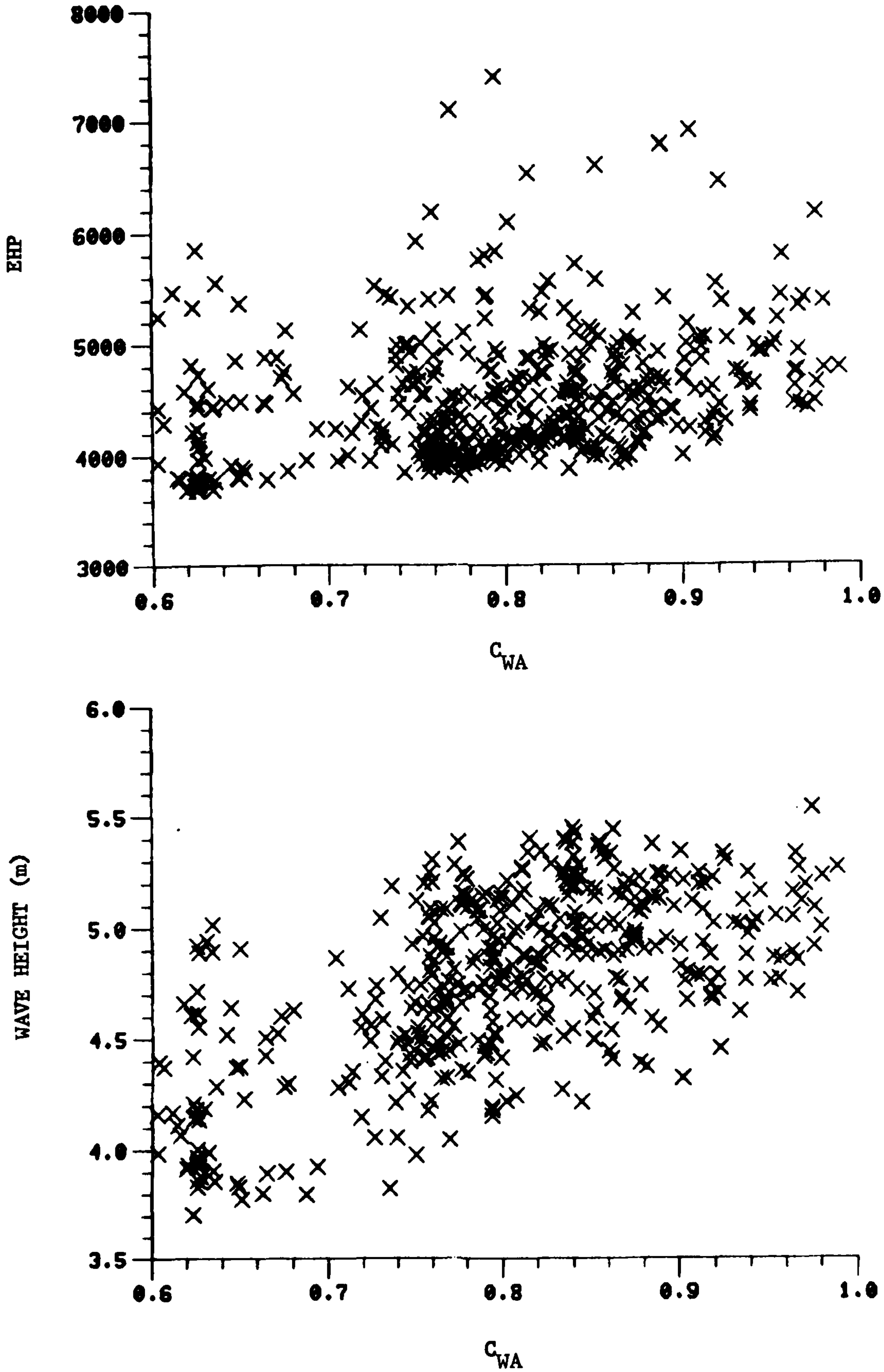

Figure 4 - Wave Height and EHP versus Water Plane Coefficient Aft

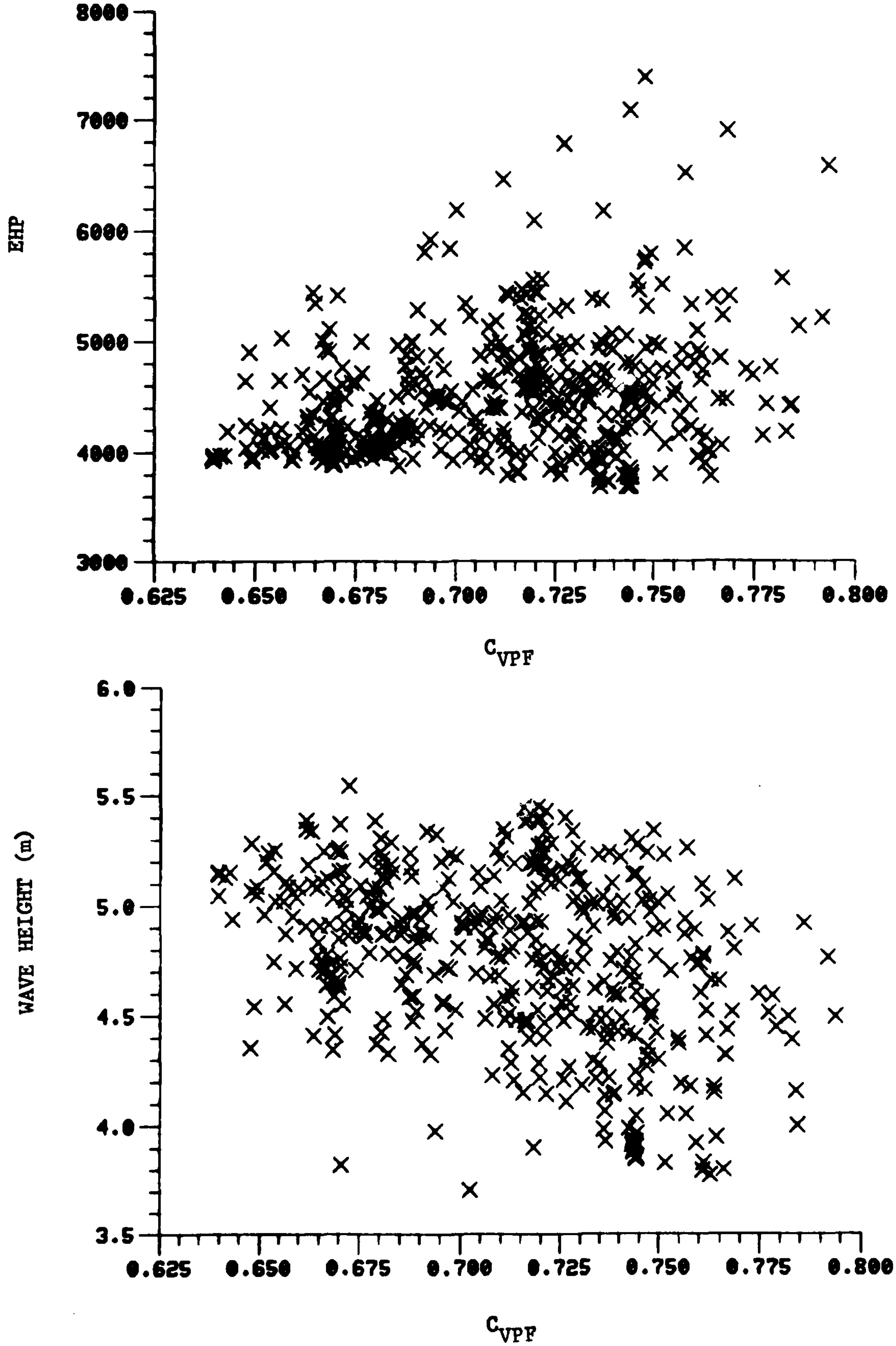

Figure 5 - Wave Height and EHP versus Vertical Prismatic Coefficient Forward

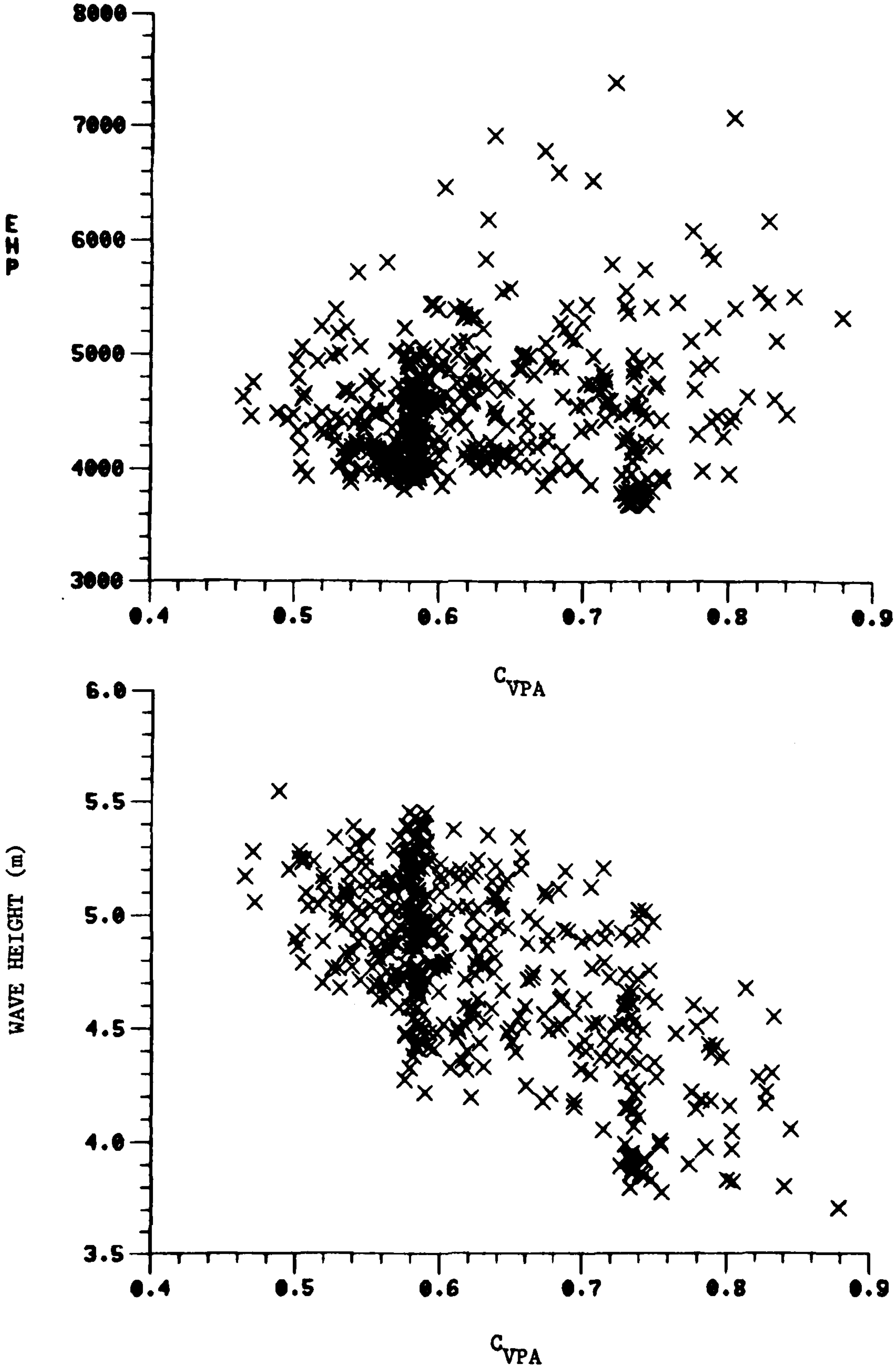

Figure 6 - Wave Height and EHP versus Vertical Prismatic Coefficient Aft

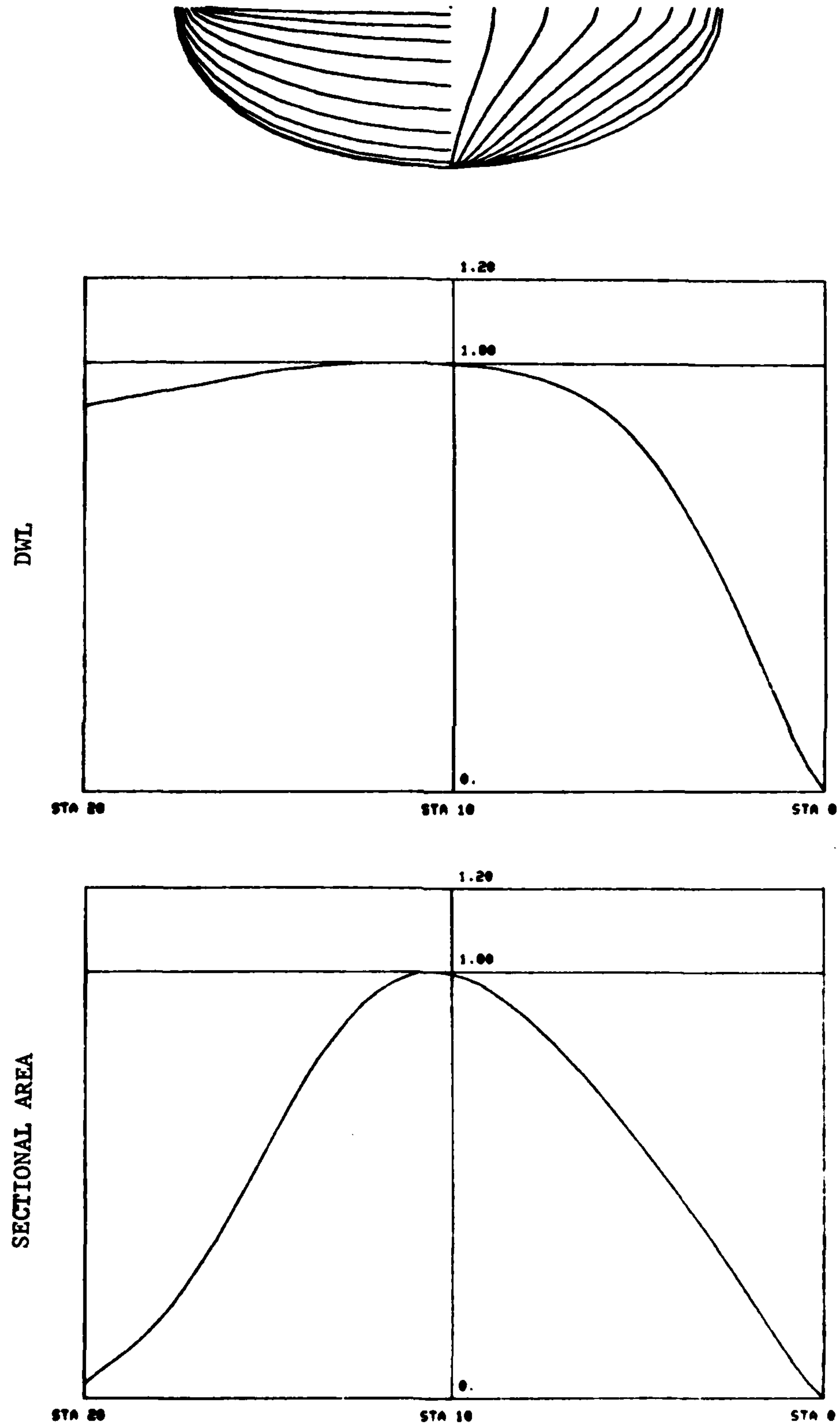

Figure 7 - 20 Knot Seakeeping Ship Hull Form

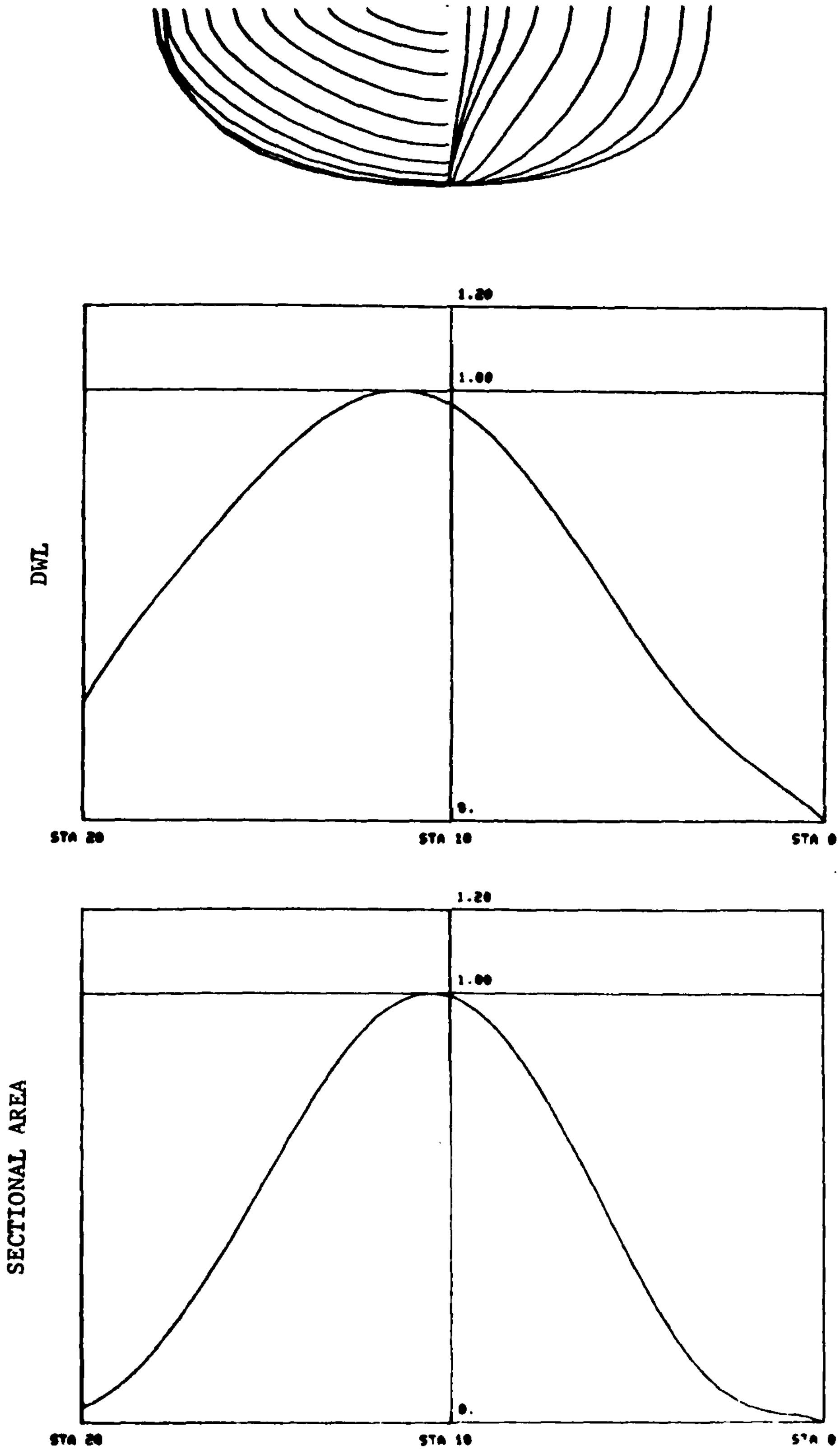

Figure 8 - 20 Knot Resistance Ship Hull Form

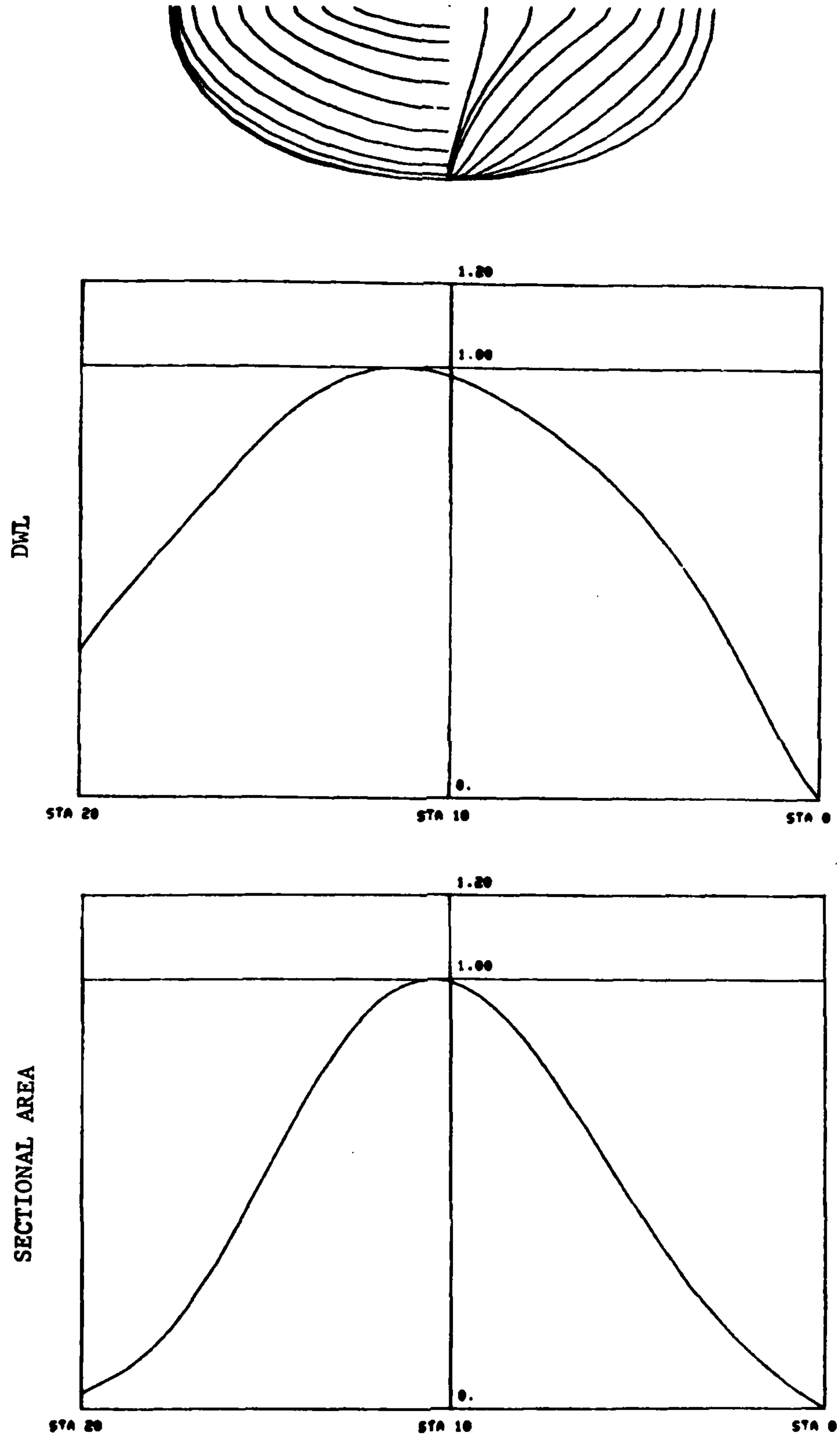

Figure 9 - 20 Knot Combination Ship Hull Form

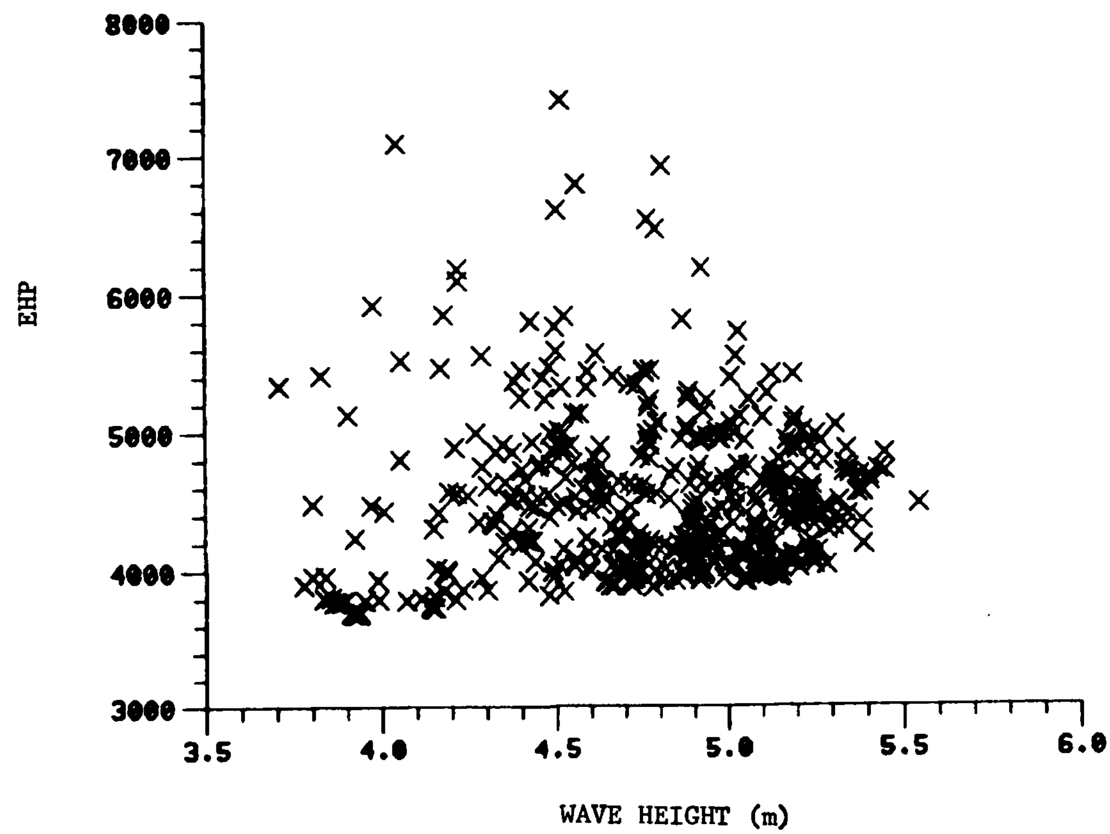

Figure 10 - EHP versus Critical Wave Height for
all 20 Knot Ships Generated

TABLE 1 - HULL FORM PARAMETER RANGES

Parameter	Low	High
C_{WPF}	0.40	0.90
C_{WPA}	0.60	1.00
C_{VPF}	0.50	0.90
C_{VPA}	0.35	1.00
T (m)	3.00	7.00
L (m)	90.00	170.00
∇ (m^3)	4300.00	4300.00
C_M	0.80	0.80

TABLE 2 - COST FUNCTION WEIGHTING FACTORS

	Wave Height			Resistance		
	10 Knots	20 Knots	30 Knots	10 Knots	20 Knots	30 Knots
Seakeeping						
10 knots	-1	--	--	0	--	--
20 knots	--	-1	--	--	0	--
30 knots	--	--	-1	--	--	0
Resistance						
10 knots	0	--	--	1	--	--
20 knots	--	0	--	--	1	--
30 knots	--	--	0	--	--	1
Combination						
10 knots	-0.574	--	--	0.019	--	--
20 knots	--	-0.733	--	--	0.002	--
30 knots	--	--	-0.685	--	--	0.00005

TABLE 3 - SEAKEEPING AND RESISTANCE CHARACTERISTICS OF OPTIMUM SHIPS

	Wave Height (meters)			Resistance (EHP)		
	10 Knots	20 Knots	30 Knots	10 Knots	20 Knots	30 Knots
Seakeeping						
10 knots	6.14	5.61	5.22	473	4400	19900
20 knots	6.14	5.61	5.22	473	4400	19900
30 knots	4.64	5.00	5.57	462	5480	37500
Resistance						
10 knots	4.40	3.85	3.60	419	3930	20300
20 knots	4.70	4.25	4.11	432	3760	16900
30 knots	4.70	4.25	4.11	432	3760	16900
Combination						
10 knots	5.81	5.22	4.92	443	4130	19300
20 knots	5.71	5.15	4.84	445	3950	17800
30 knots	6.00	5.57	5.37	461	4340	20800

TABLE 4 - HULL FORM PARAMETERS OF OPTIMUM SHIPS

	Seakeeping	Resistance	Combination
10 Knot			
C_{WPF}	0.686	0.498	0.668
C_{WPA}	0.965	0.602	0.771
C_{VPF}	0.664	0.767	0.677
C_{VPA}	0.470	0.809	0.597
T (m)	4.26	4.23	4.47
L (m)	149.00	136.88	145.16
B (m)	14.90	17.11	14.53
20 Knot			
C_{WPF}	0.686	0.462	0.606
C_{WPA}	0.965	0.758	0.776
C_{VPF}	0.664	0.723	0.640
C_{VPA}	0.470	0.585	0.560
T (m)	4.26	4.76	4.62
L (m)	149.00	145.43	147.70
B (m)	14.90	15.99	15.32
30 Knot			
C_{WPF}	0.719	0.462	0.735
C_{WPA}	0.986	0.758	0.905
C_{VPF}	0.674	0.723	0.664
C_{VPA}	0.464	0.585	0.487
T (m)	5.25	4.76	4.55
L (m)	105.10	145.43	141.34
B (m)	16.59	15.99	14.38

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